Università degli Studi di Napoli "Federico II"

SCUOLA POLITECNICA E DELLE SCIENZE DI BASE

DEPARTMENT OF INDUSTRIAL ENGINEERING

Master Degree dissertation in

AEROSPACE AND ASTRONAUTIC EINGNEERING

Automatic Aero-Structural Analysis and Aerodynamic Optimization for Collaborative Aircraft Design Process

Deutsches Zentrum für Luft- und Raumfahrt

Supervisor:

Prof. Ing. Pierluigi Della Vecchia

Co-supervisor:

Dott. Ing. Francesco Torrigiani

Candidate:

Massimo Mandorino

M53/0881

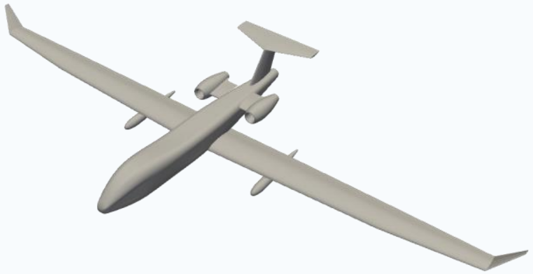
CONTENTS

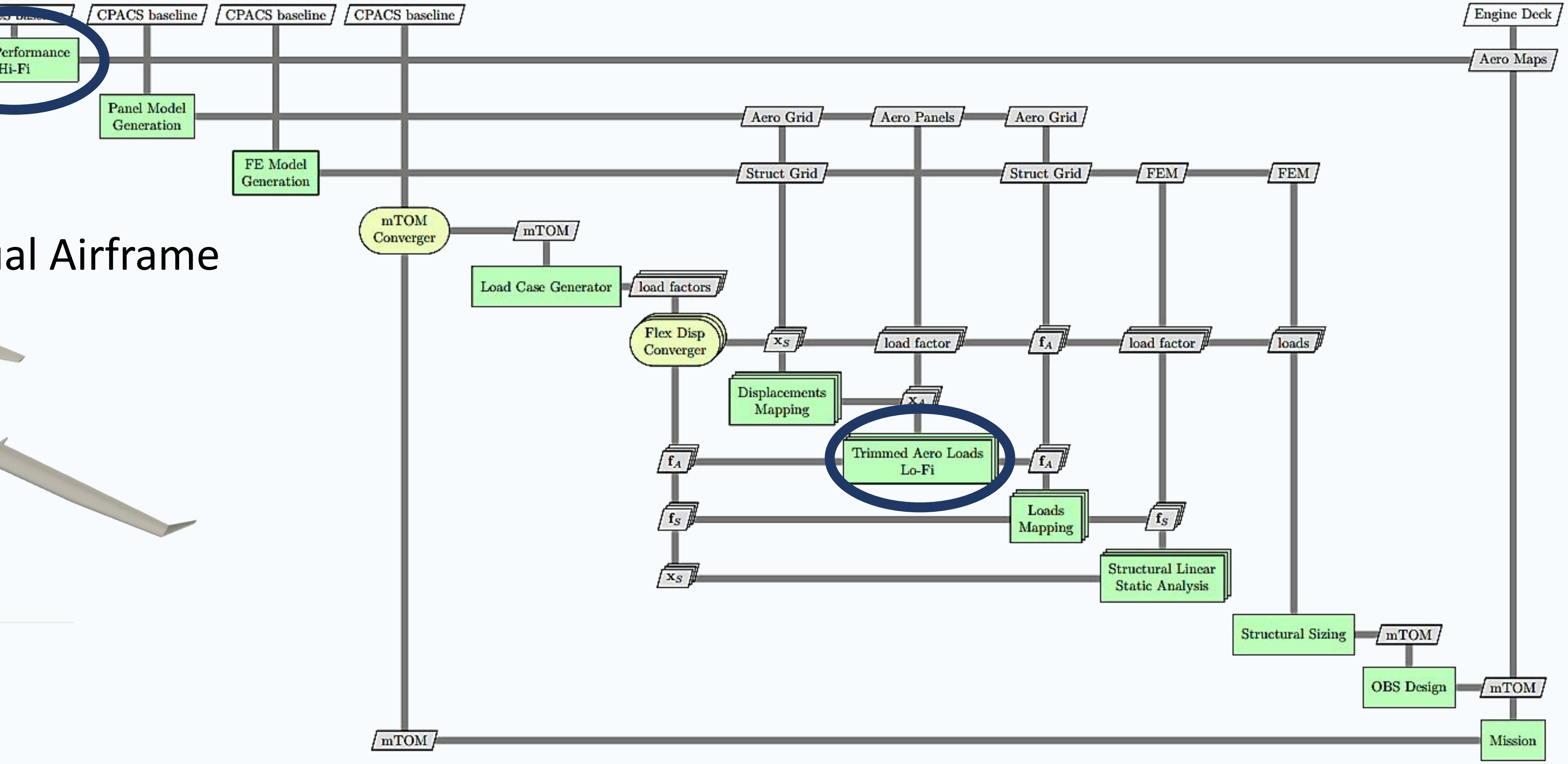
COLLABORATIVE MULTIDISCIPLINARY DESIGN

- AGILE 4.0 project
- Cooperation UNINA-DLR
- Development of remote accessible **Tools**

- MDO / MBSE technologies

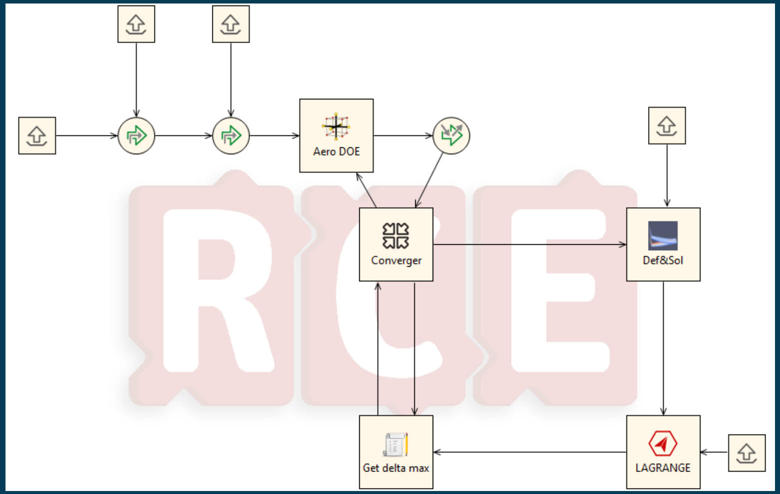
Use Case 5 – Virtual Airframe





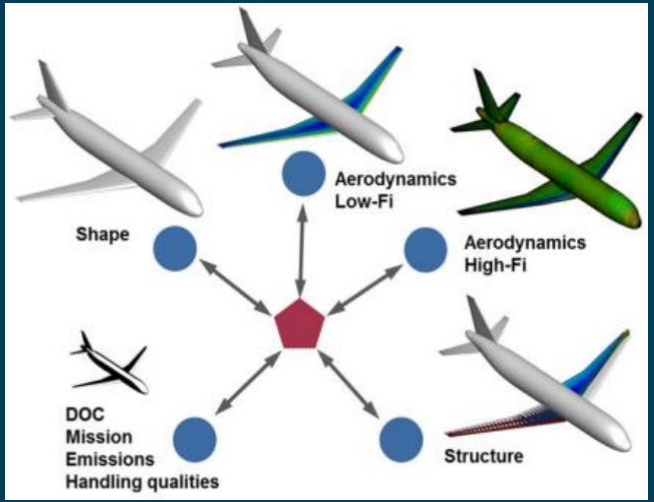
INSTRUMENTS FOR COLLABORATIVE DESIGN

INTEGRATION FRAMEWORK



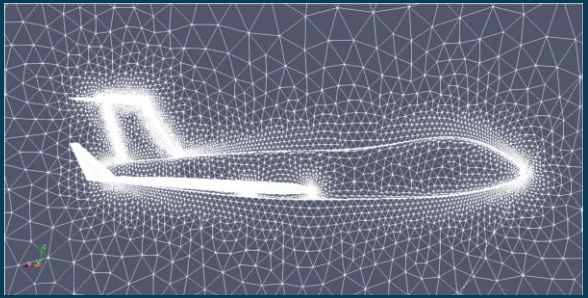
Employed Integrator:
Remote Component Environment

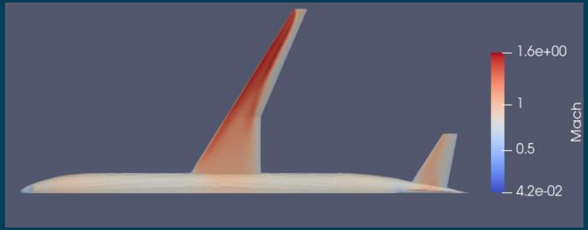
CENTRALIZED DATA FORMAT



Selected Format:
CPACS, Common Parametric Aircraft Configuration Schema

ANALYSIS MODULES





Tools to be executed:
Pointwise, SU2, Python-based developed codes

ANALYSIS MODULES

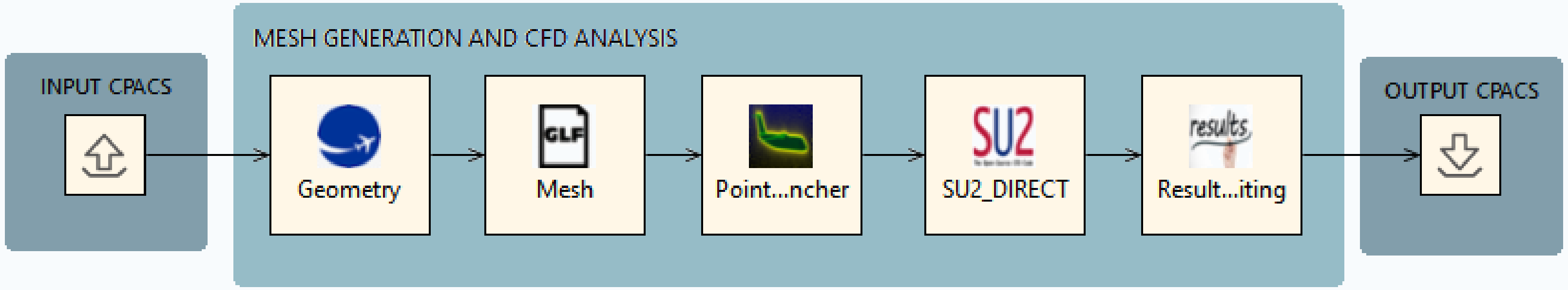
- Mesh Generation and Aerodynamic Analysis
- Structural Analysis
- Aerodynamic Optimization
- Aero-Structural Analysis
- CPACS Results and Geometry Update

PROVIDED BY UNINA AND DLR

DLR Deutsches Zentrum für Luft- und Raumfahrt

DEVELOPED BY THE AUTHOR

MESH GENERATION AND AERODYNAMIC ANALYSIS



Input: CPACS Format File

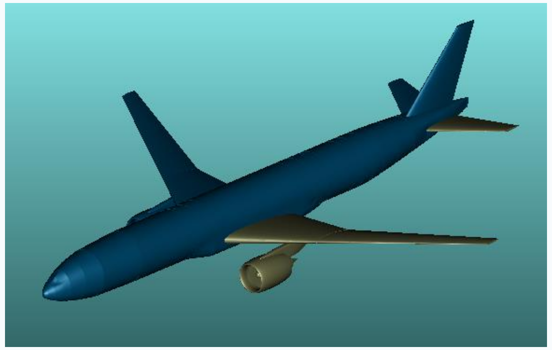
Mesh Generation

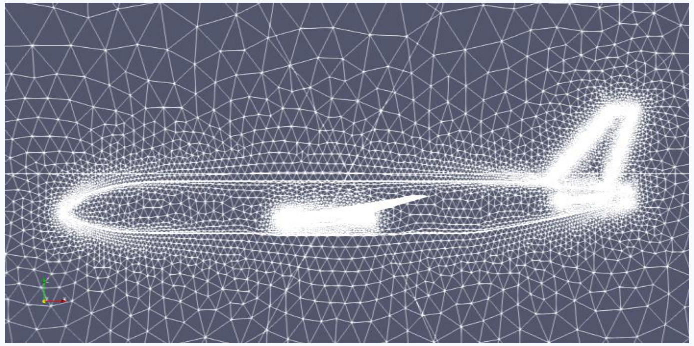
CFD Analysis

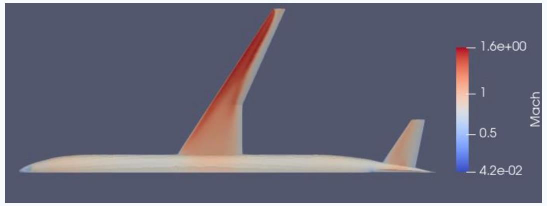
Geometry and CFD Parameters

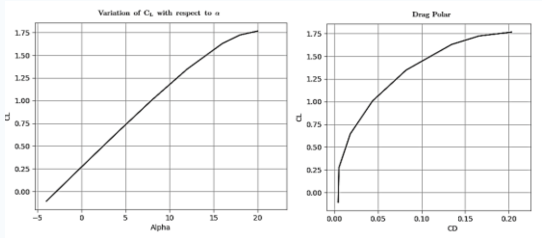
Volumetric and Surface Mesh

Nodal and Total Results



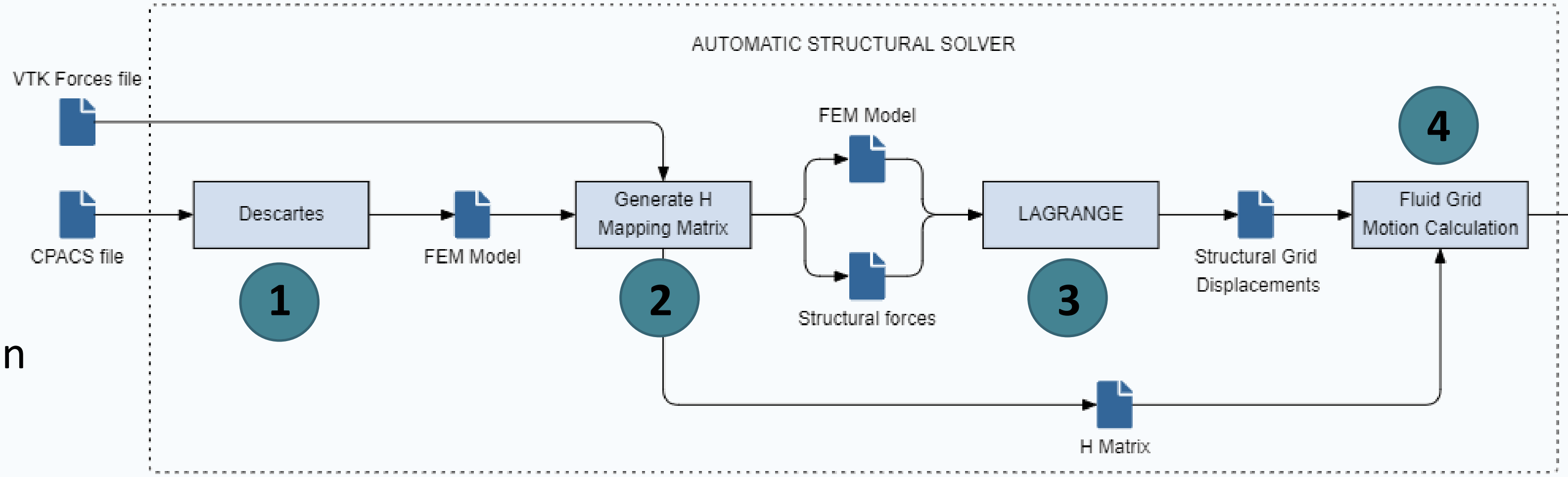






LAGRANGE STRUCTUAL ANALYSIS TOOL

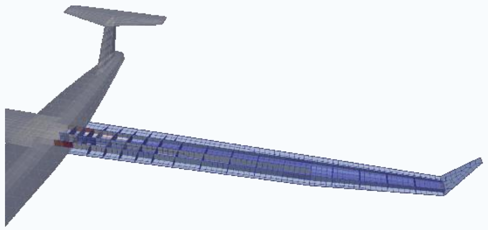
INPUT
- CPACS File
- Cell forces distribution



OUTPUT
Nodal mesh displacements

1

- ➢ Structural mesh



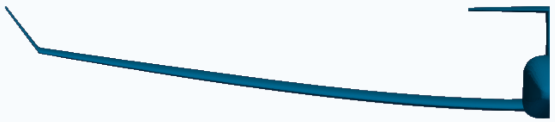
2

- ➢ Interpolation mapping matrix H
- ➢ Structural grid Forces distribution

$$f_{structure} = H * f_{fluid}$$

3

- ➢ Static structural analysis
- ➢ Nodes motion

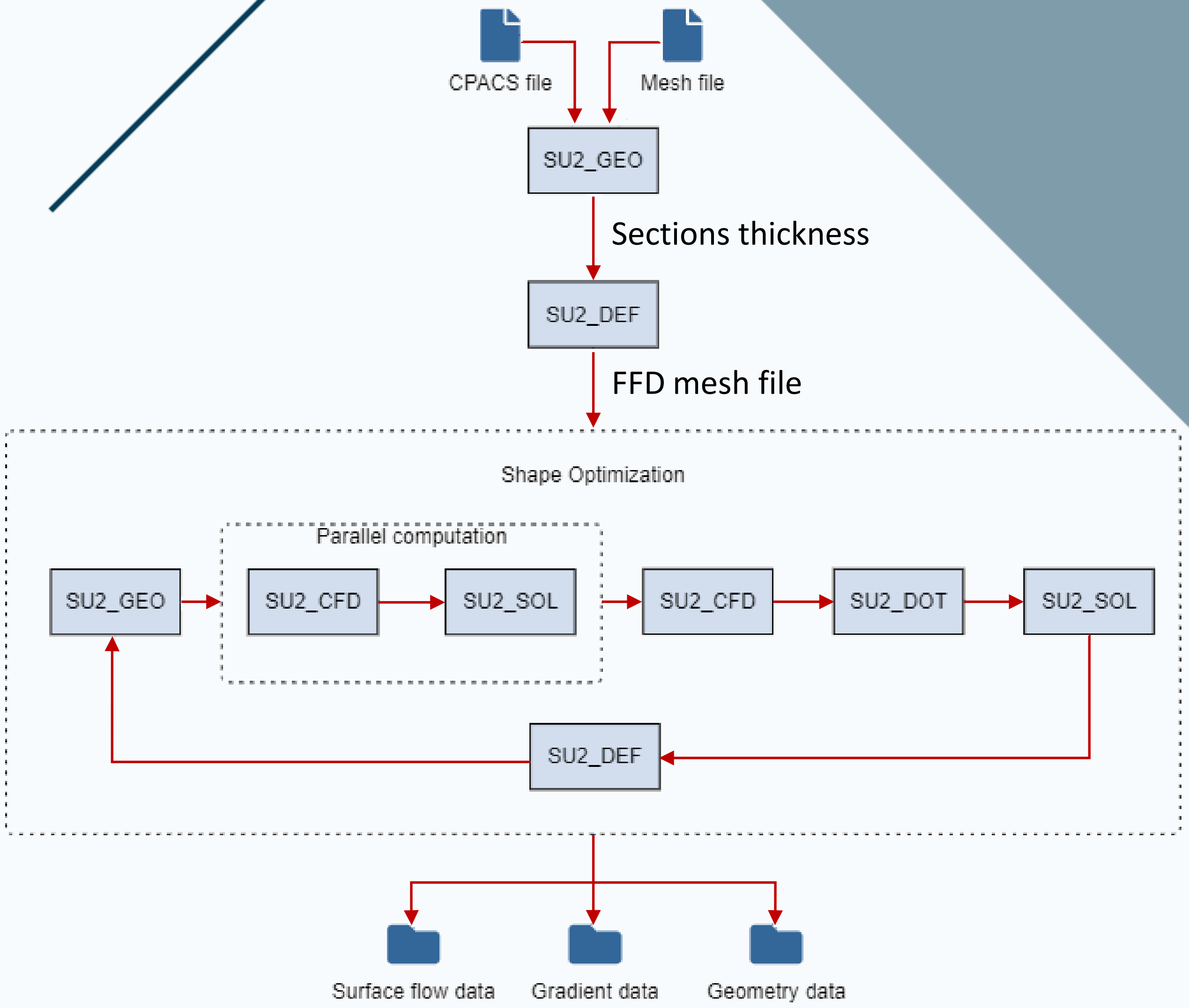


4

- ➢ Fluid nodes displacement

$$u_{fluid} = H^T * u_{structure}$$

AERODYNAMIC OPTIMIZATION



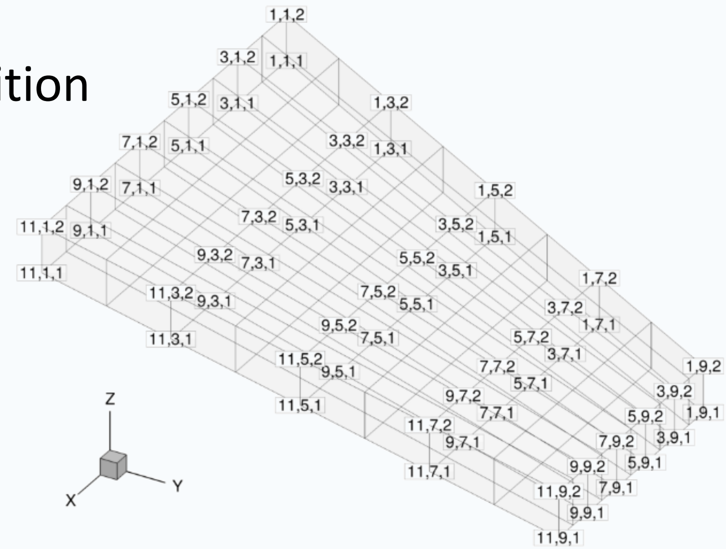
INPUT
- CPACS file
- SU2 mesh file

OUTPUT for each iteration
- Aerodynamic and gradient nodal data
- Shape geometry

1. Geometrical parameters

Section Thickness

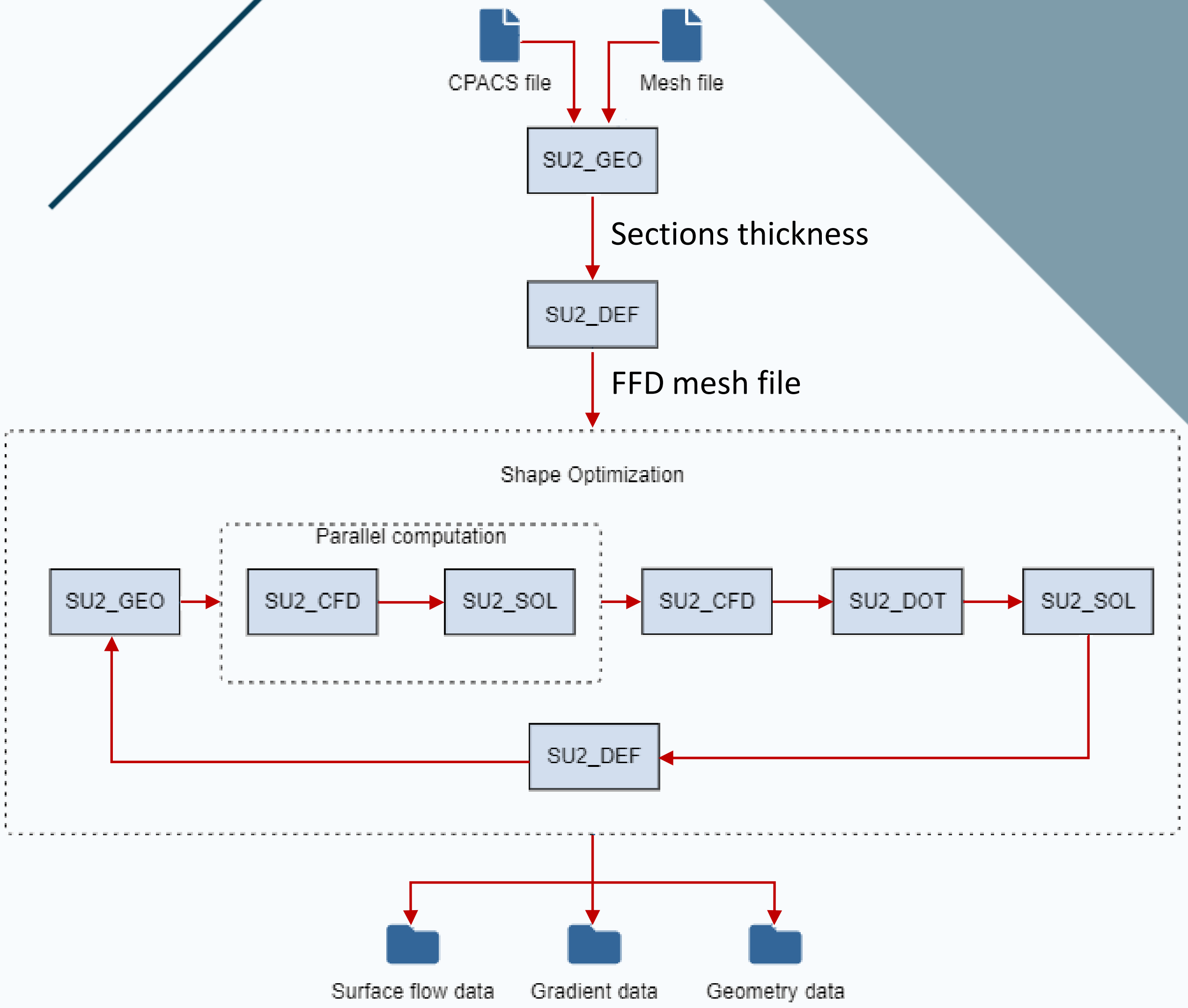
2. FFD box definition



3. Shape optimization loop SU2 code

- **Optimization Methodology**: Adjoint formulation
- **Design Variable**: FFD control points

AERODYNAMIC OPTIMIZATION



FLOW BASED OBJECTIVE FUNCTIONS AND CONSTRAINTS

Aerodynamic forces: Drag, Lift, Side-force, Efficiency, X Y Z Force and Moment

Flow parameters: Nearfield pressure, Total heat-flux, Maximum heat-flux, Surface total pressure, Surface static pressure, Surface mass-flow, Surface Mach number

GEOMETRICAL OBJECTIVE FUNCTIONS AND CONSTRAINTS

Airfoil area, thickness, chord, toc, twist

Wing volume, max and min thickness, chord, toc, twist, curvature, dihedral

Station width, area, thickness, chord, toc, twist

DESIGN VARIABLES

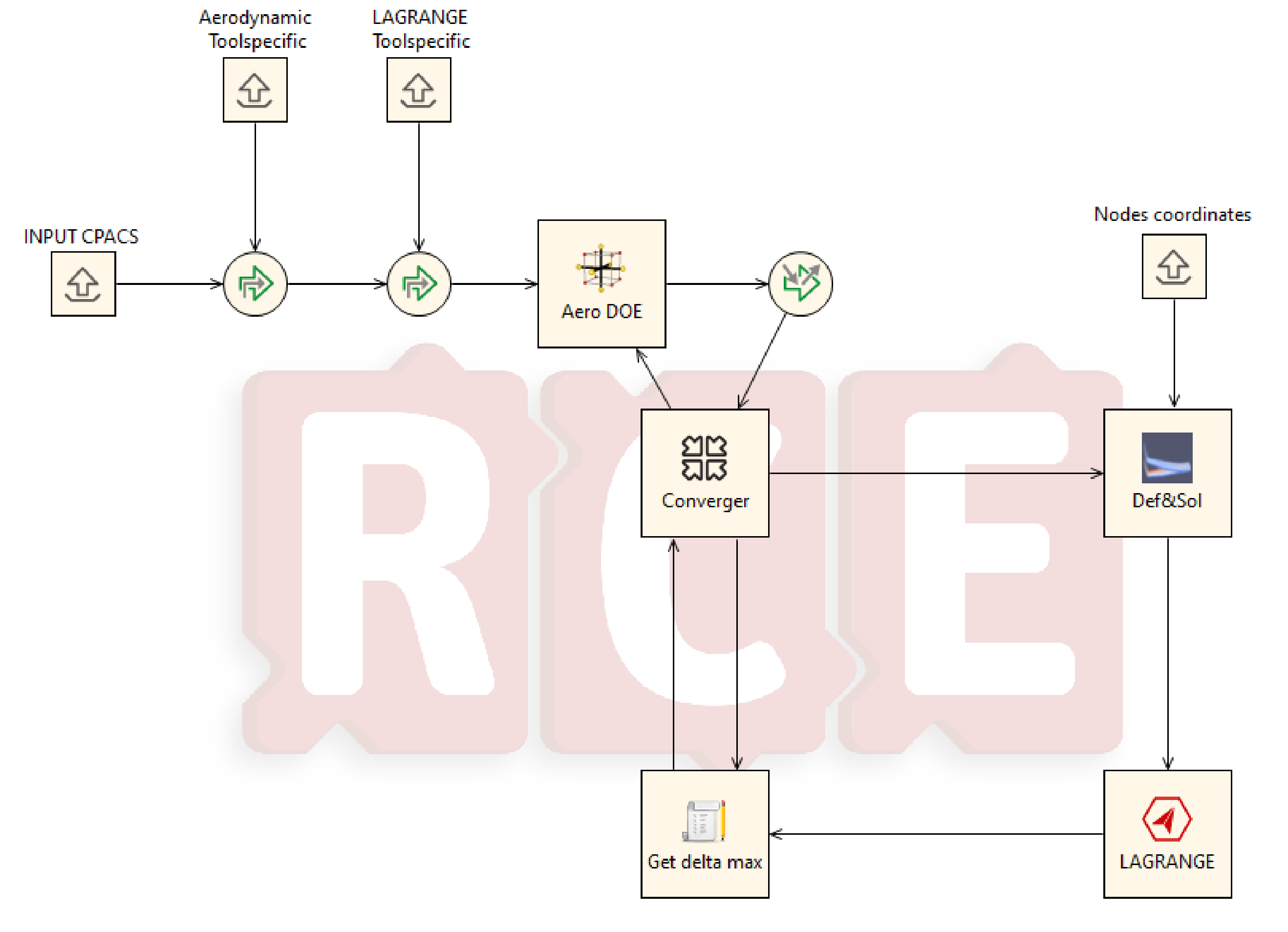
FFD Translation, Rotation

Control Point Displacement

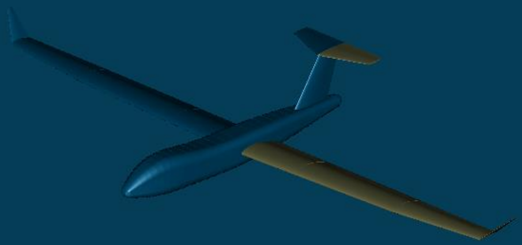
Local Dihedral angle, Twist angle, Camber, Thickness, Twist

Custom design variable

AERO-STRUCTURAL ANALYSIS WORKFLOW

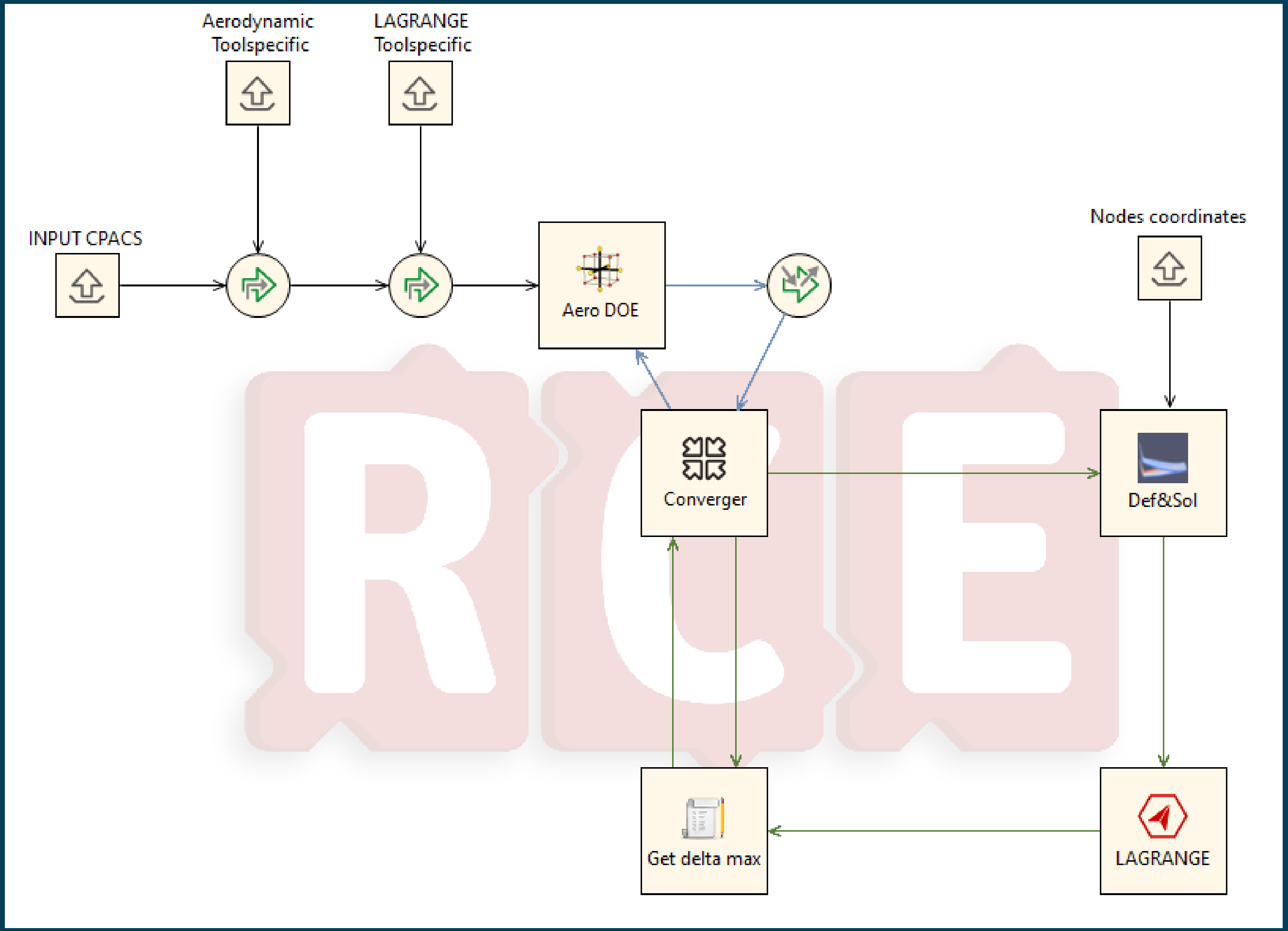


INPUT
- CPACS File
- SU2 Mesh File
- Input nodal mesh coordinates



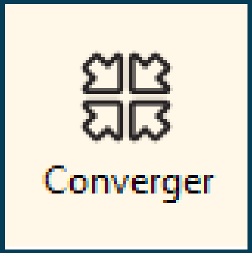
OUTPUT for each iteration
- Aerodynamic nodal data
- Mesh forces distribution
- Shape Geometry

AERO-STRUCTURAL ANALYSIS WORKFLOW



External loop

1. Tool specific update.
2. Internal loop execution.

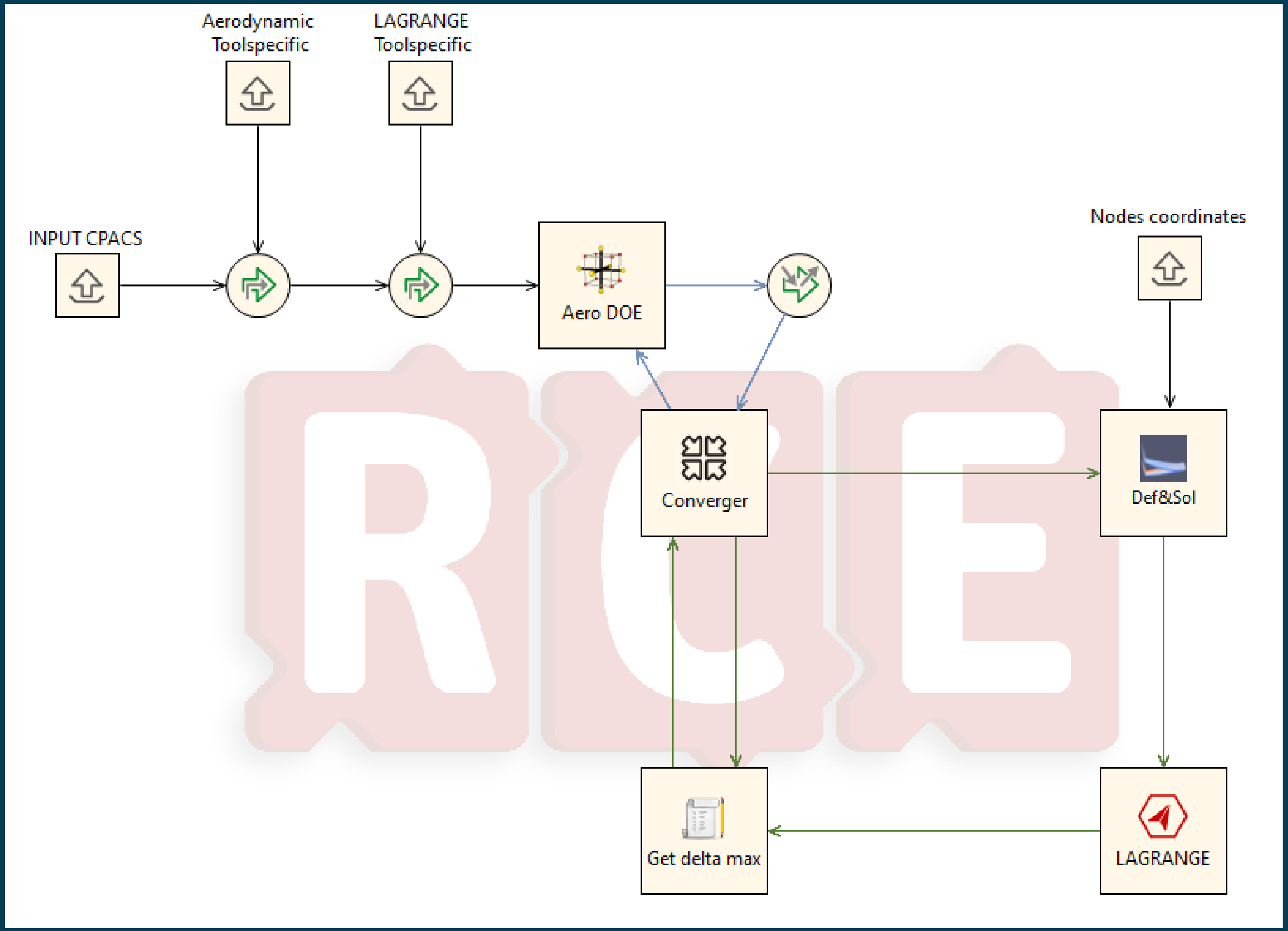


Internal loop

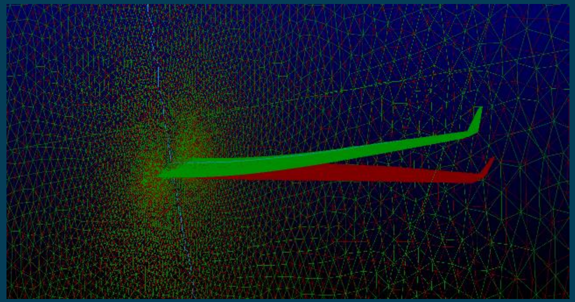
Aero-structural equilibrium

Iteration convergence loop

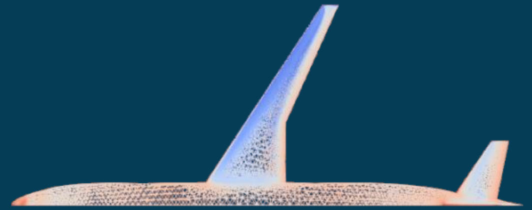
AERO-STRUCTUAL ANALYSIS WORKFLOW



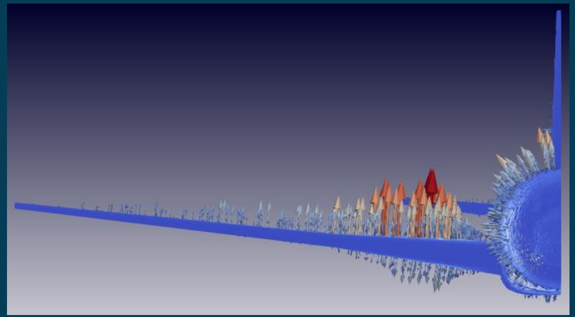
1. Mesh Deformation



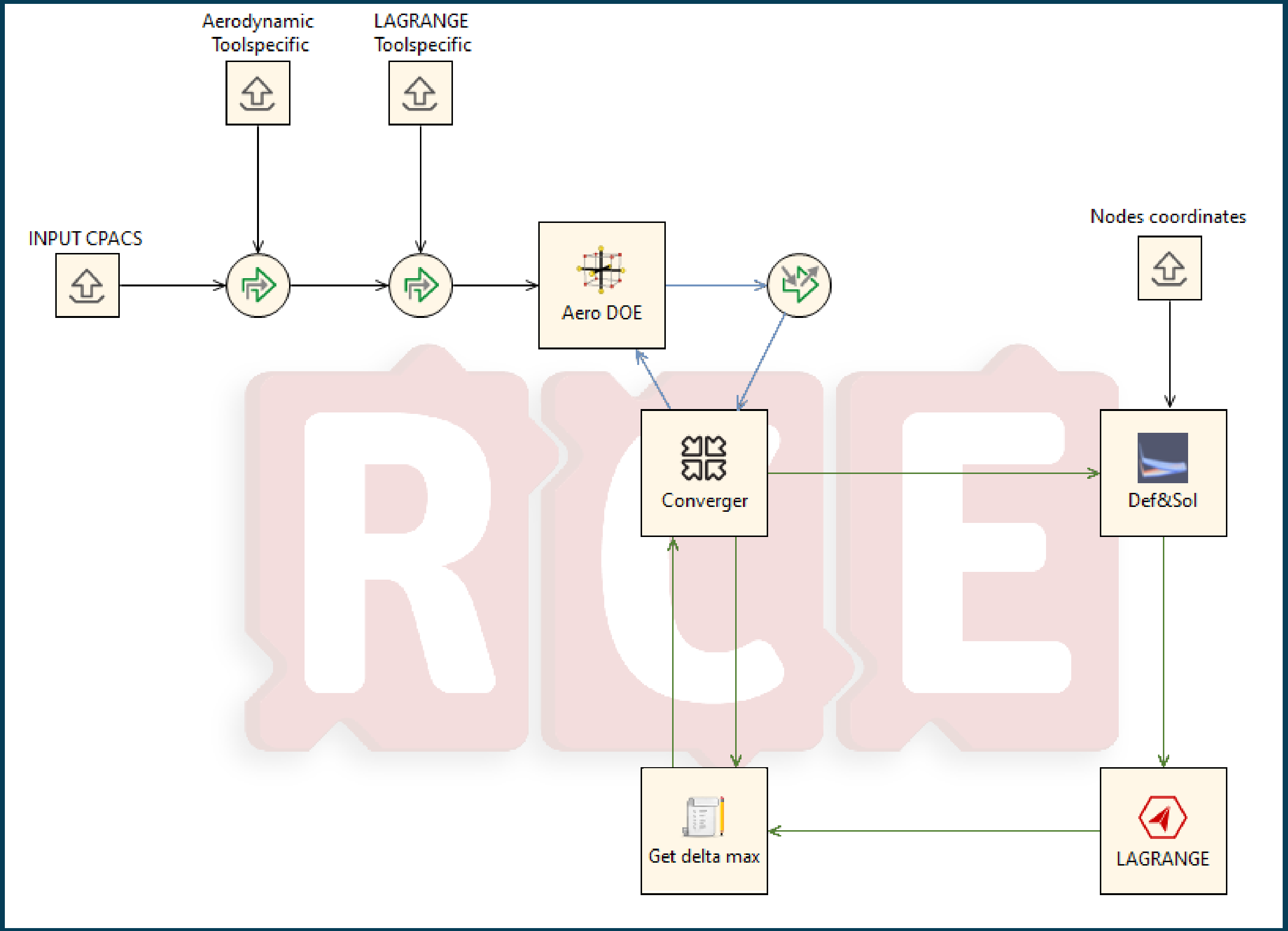
2. CFD analysis



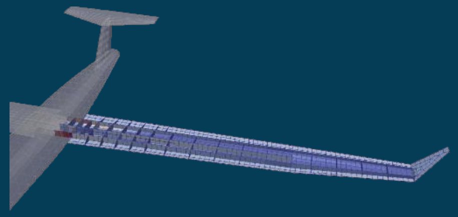
3. Cell Forces



AERO-STRUCTURAL ANALYSIS WORKFLOW

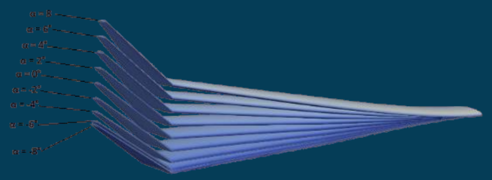


CSD Analysis



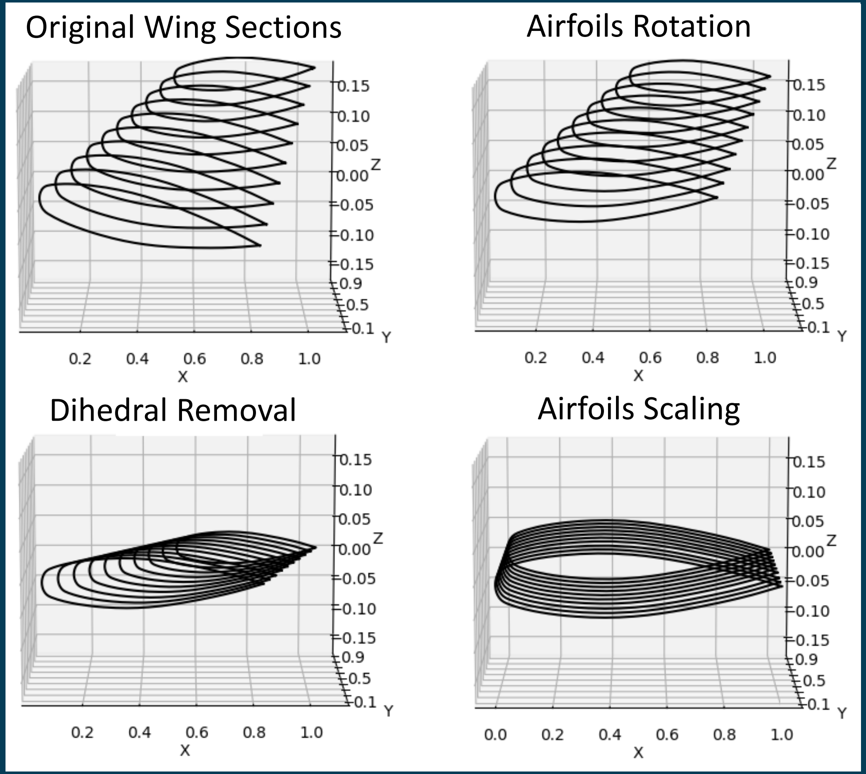
Get delta max

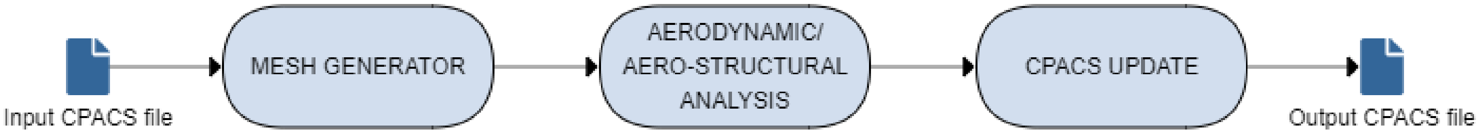
Max deformation



CPACS RESULTS AND GEOMETRY UPDATE

1. Get new wing shape
2. Airfoil points compatible with CPACS

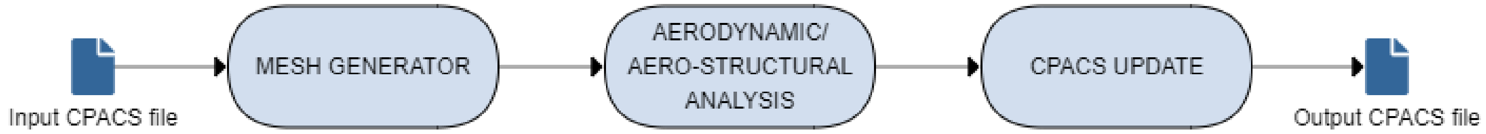


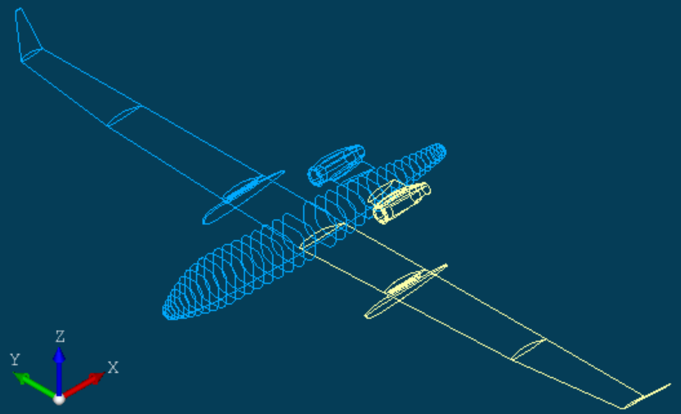


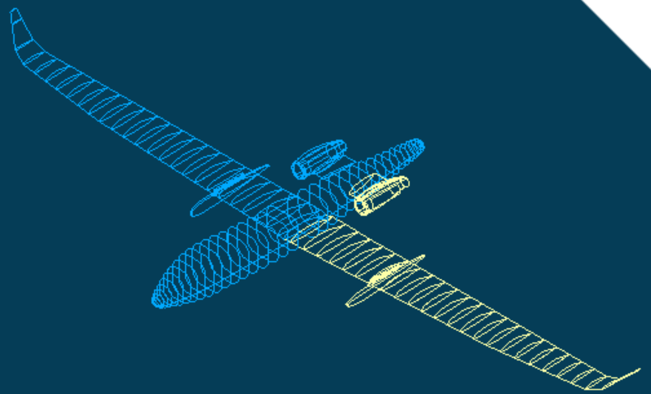
This tools allow to develop a complete **collaborative workflow**. Aerodynamic results and the new shape can be insert in CPACS file.

CPACS RESULTS AND GEOMETRY UPDATE

1. Get new wing shape
2. Airfoil points compatible with CPACS
3. Update CPACS wing geometry

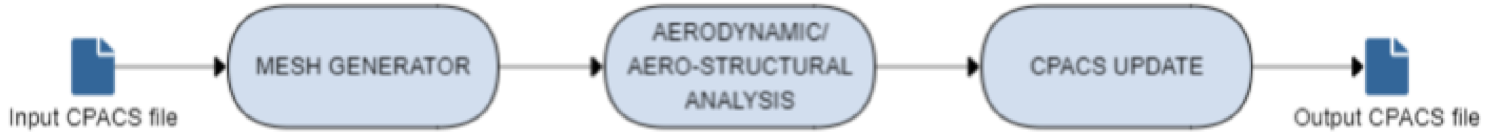


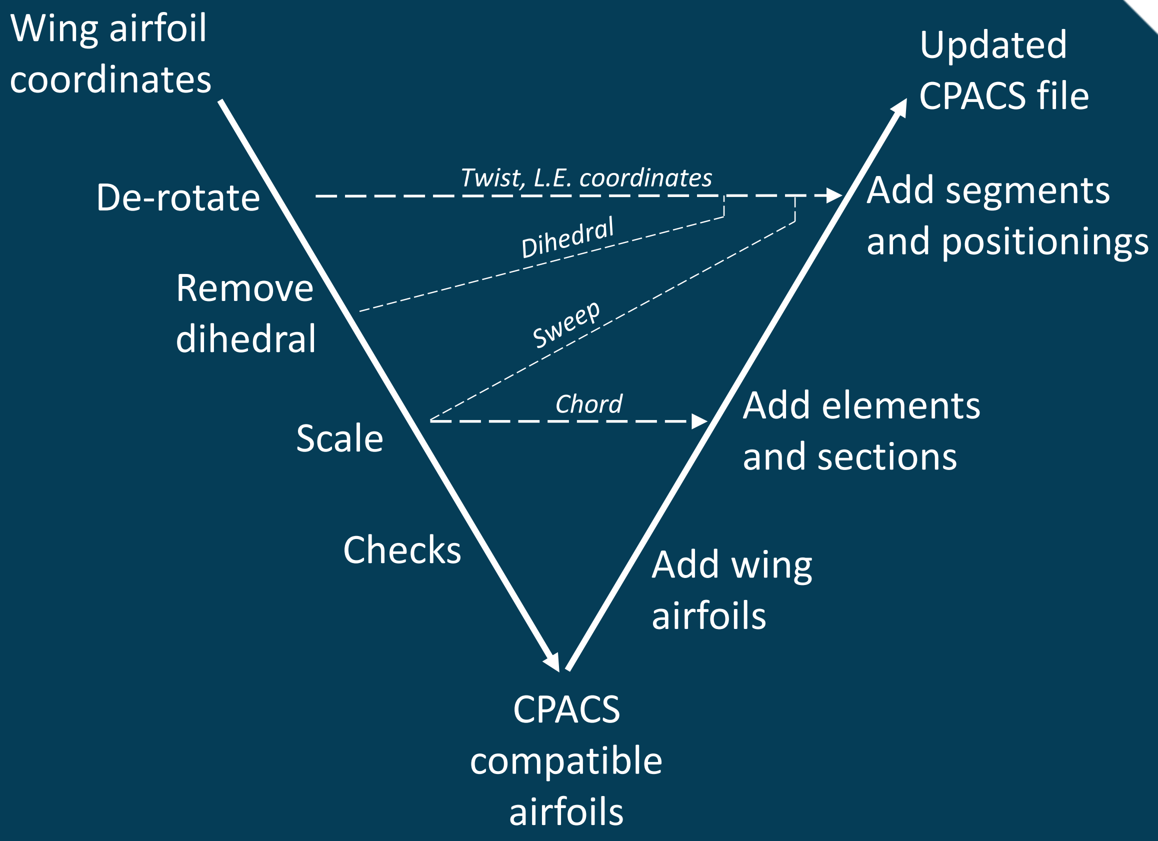




This tools allow to develop a complete **collaborative workflow**. Aerodynamic results and the new shape can be insert in CPACS file.

CPACS RESULTS AND GEOMETRY UPDATE





This tools allow to develop a complete **collaborative workflow.** Aerodynamic results and the new shape can be insert in CPACS file.

TEST CASE: OPTIMALE CONFIGURATION

OPTIMALE consists of a conventional low wing configuration with T-tail and two rear mounted turbofan engines.

One reference missions consist of **area surveillance**. It is characterized by a **loitering** segment after the cruise.

Geometrical data

Wing surface	55.2 m^2
Aspect Ratio	19
Fuselage length	13.8 m
Sweep angle	3° before kink; 7.5° after kink
Dihedral angle	0°
Mean aerodynamic chord	1.8 m

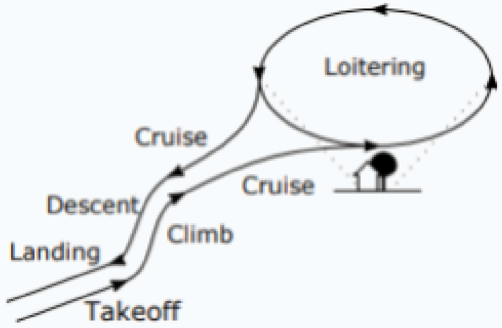
TEST CASE: OPTIMALE CONFIGURATION

OPTIMALE consists of a conventional low wing configuration with T-tail and two rear mounted turbofan engines.

One reference missions consist of **area surveillance**. It is characterized by a **loitering** segment after the cruise.

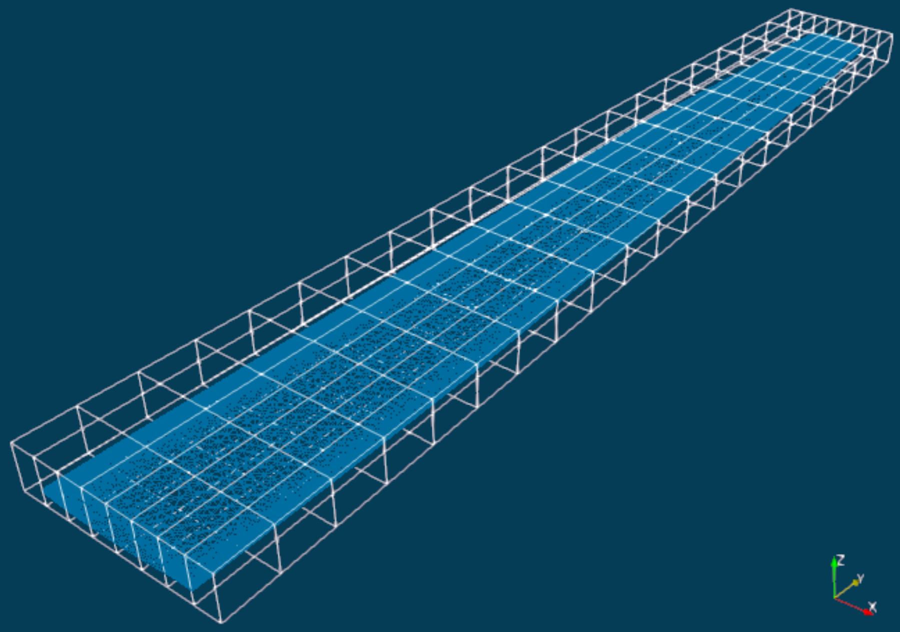
Mission Requirements

Cruise altitude above civil transport	> 15 km
Loitering altitude	7.5 km – 13.5 km
Range	> 12000 km
Endurance	> 20 h
Runways length	2500 m
Cruise speed	Mach Number 0.5 (150 m/s)
Dive speed	Mach Number 0.6 (180 m/s)
Landing speed	Mach Number 0.16 (55 m/s)
Payload weight	800 kg
Take-off weight	10000 kg



WING SHAPE OPTIMIZATION AT DIVE SPEED

Analysis conditions	
Mach number	0.6
Reynolds number	4.5*1E6
Altitude	15000 m
Fixed value of Lift Coefficient	0.85
Sideslip angle	0°



Physical problem: Eulerian Compressible

Flow condition: CL fixed

Number of cells: 2.15 millions

Objective function: Drag

Method: Adjoint Optimization

Design variables: 378 FFD points

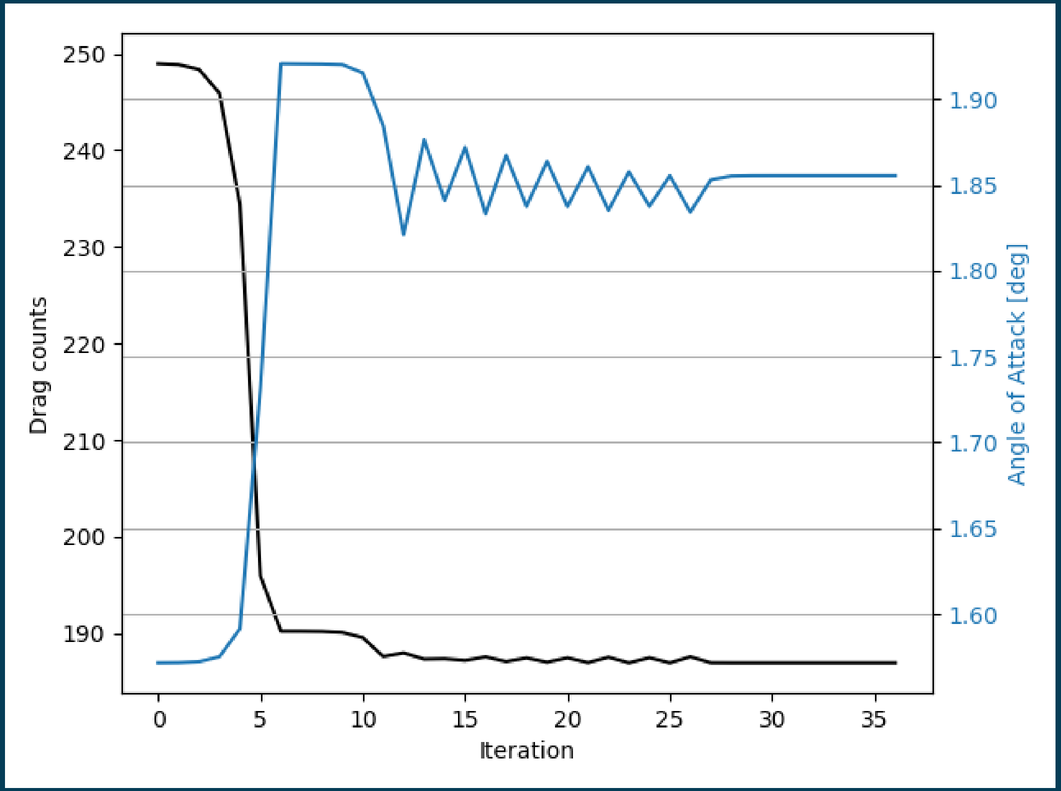
Possible displacement: z direction

Constraint: Thickness > 0.95 %

WING SHAPE OPTIMIZATION AT DIVE SPEED

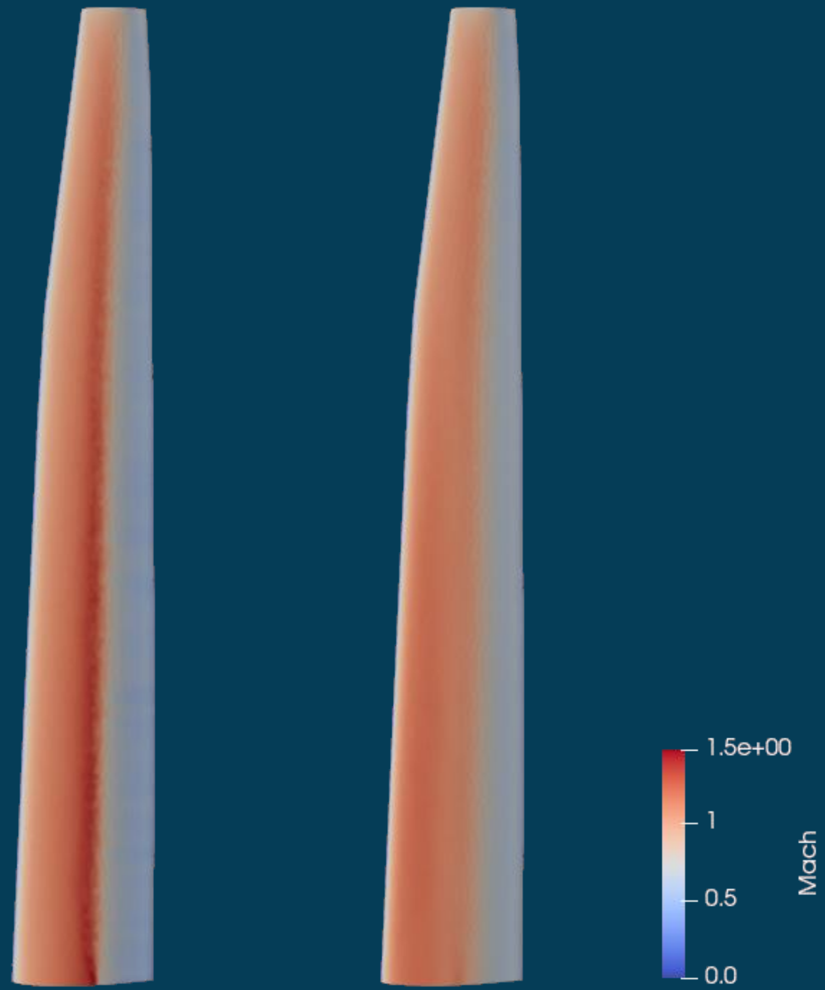
Number of iterations: 37
Computational time: 2 days
Number of cores: 32

Mach number: 0.6
Reynolds number: 4.5*1E6



CL = 0.85
CD = 0.0249

CL = 0.85
CD = 0.0187



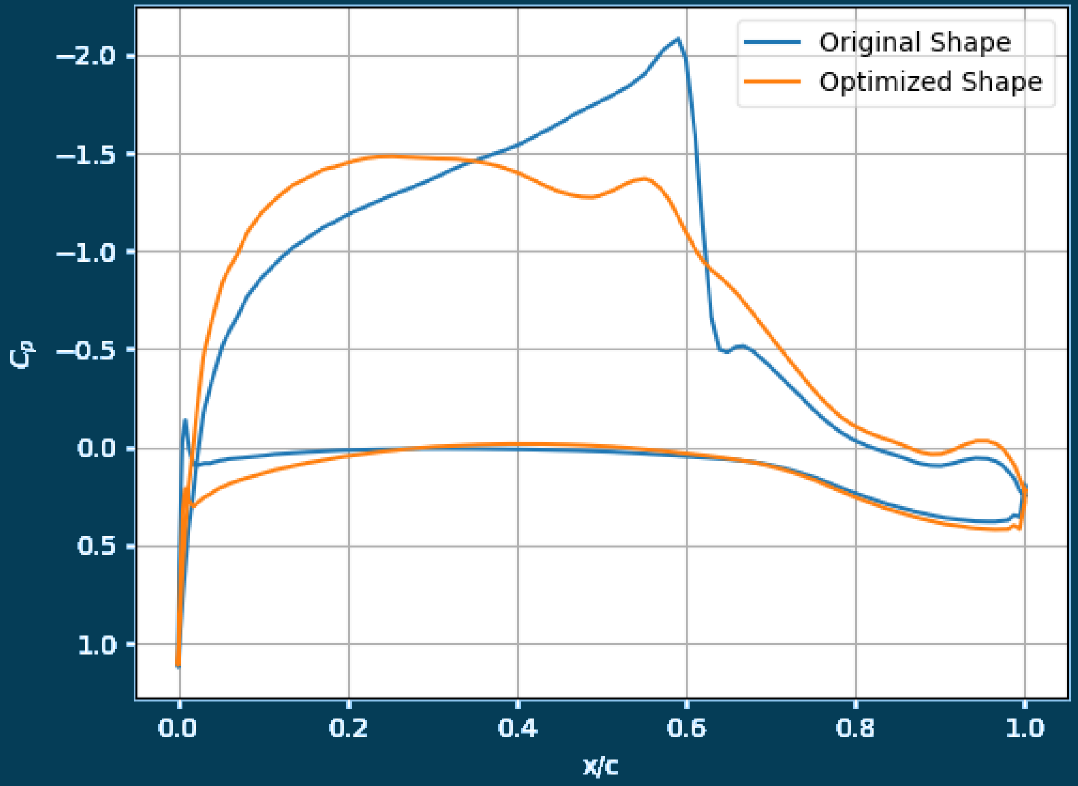
Original Wing

Optimized Wing

WING SHAPE OPTIMIZATION AT DIVE SPEED

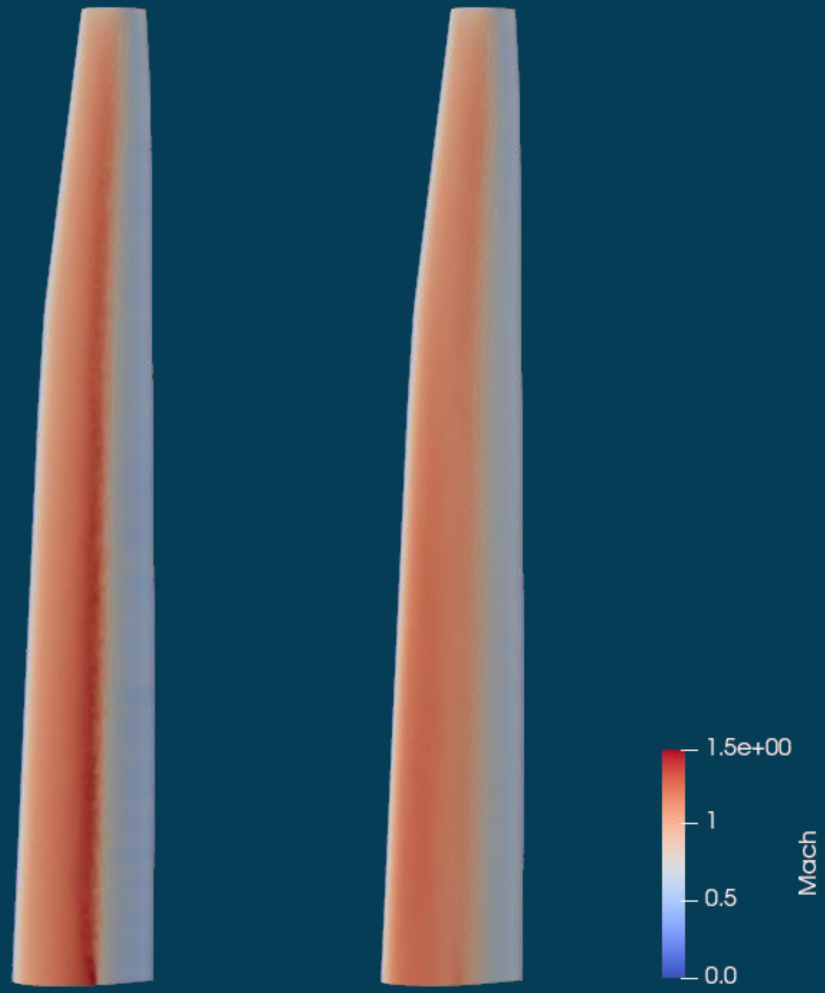
Number of iterations: 37
Computational time: 2 days
Number of cores: 32

Mach number: 0.6
Reynolds number: 4.5*1E6



CL = 0.85
CD = 0.0249

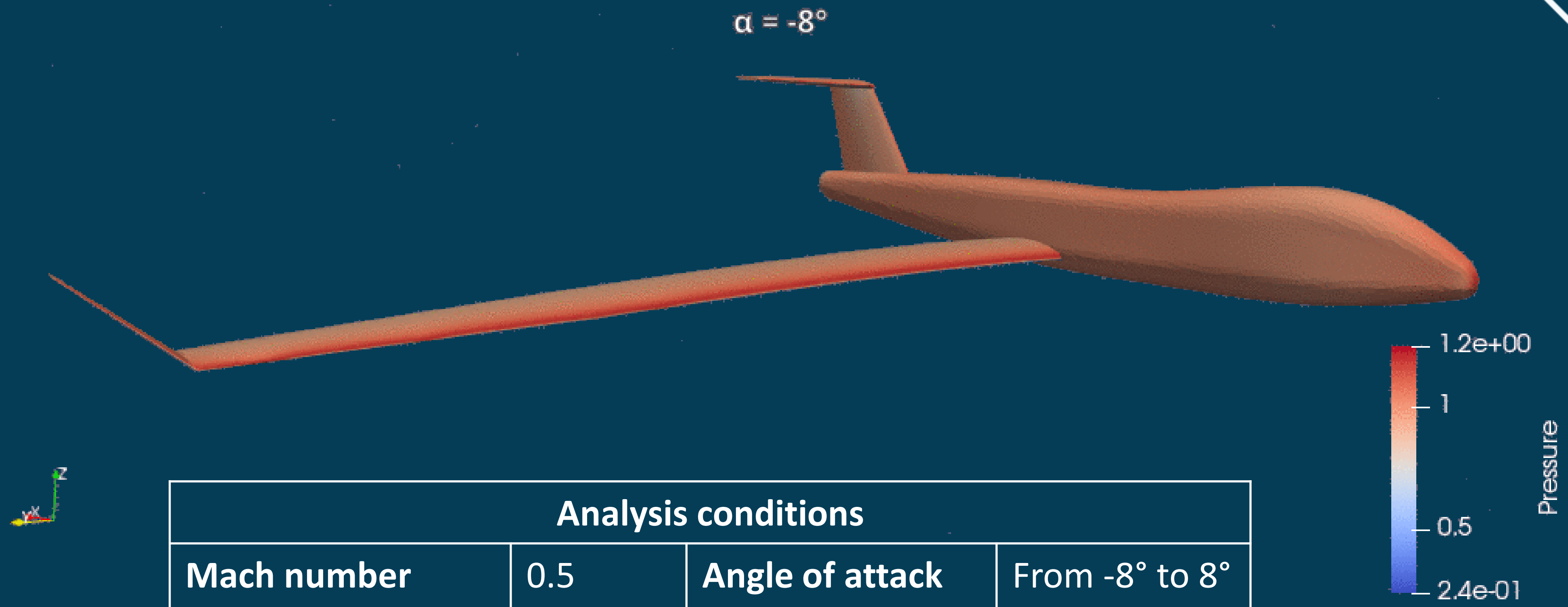
CL = 0.85
CD = 0.0187



Original Wing

Optimized Wing

OPTIMALE WING FLEXIBLE POLAR ANALYSIS



Analysis conditions			
Mach number	0.5	**Angle of attack**	From -8° to 8° with a 2° step
Reynolds number	4.5*1E6	**Sideslip angle**	0°
Altitude	13500 m	**Aircraft weight**	10000 kg
Load factor	1	**Number of cores**	8

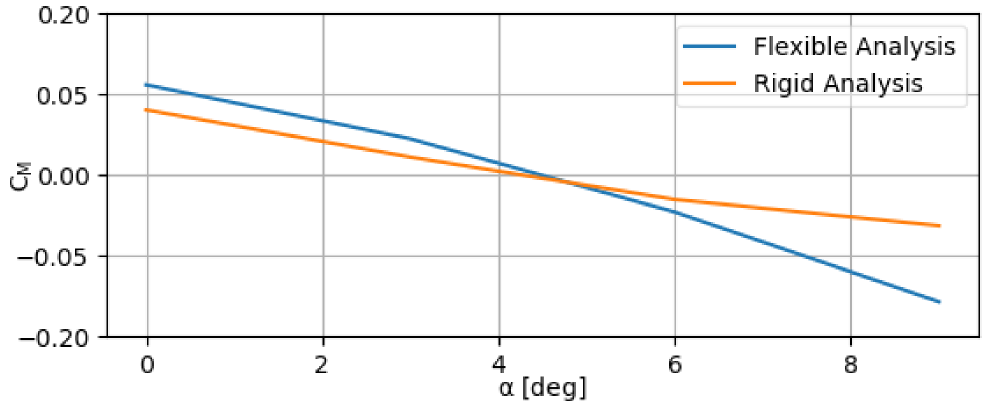
Computational time: 1 day and half

Range of maximum deformation:

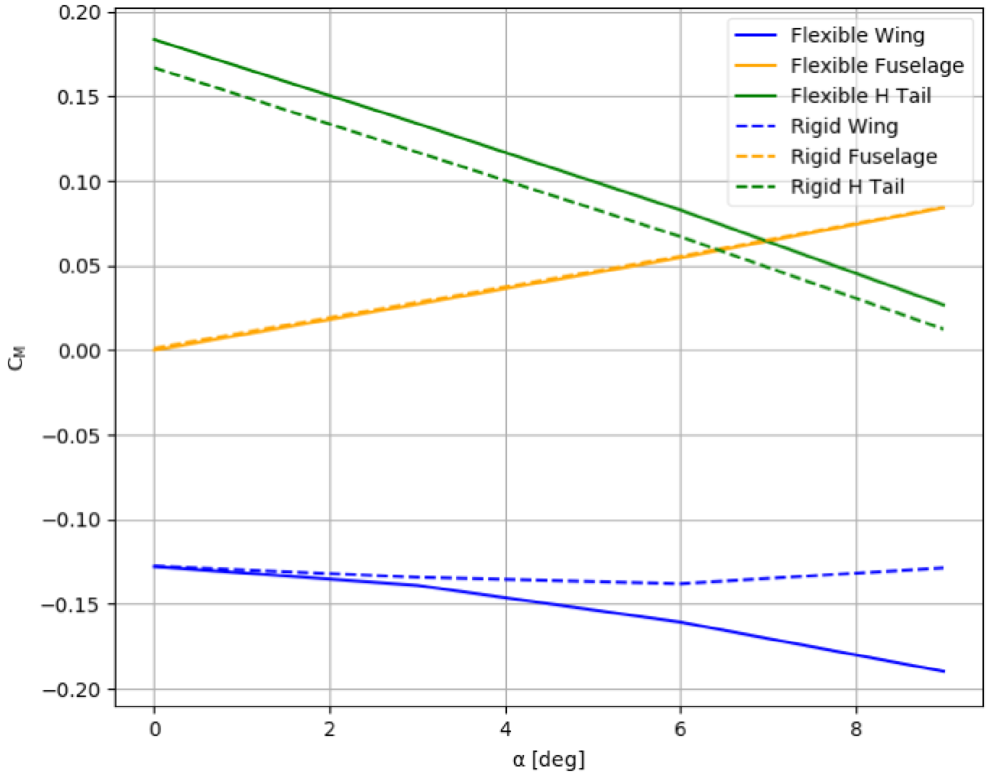
[-0.9 ; 1.3] m

OPTIMALE FLEXIBLE POLAR ANALYSIS

TOTAL AIRCRAFT

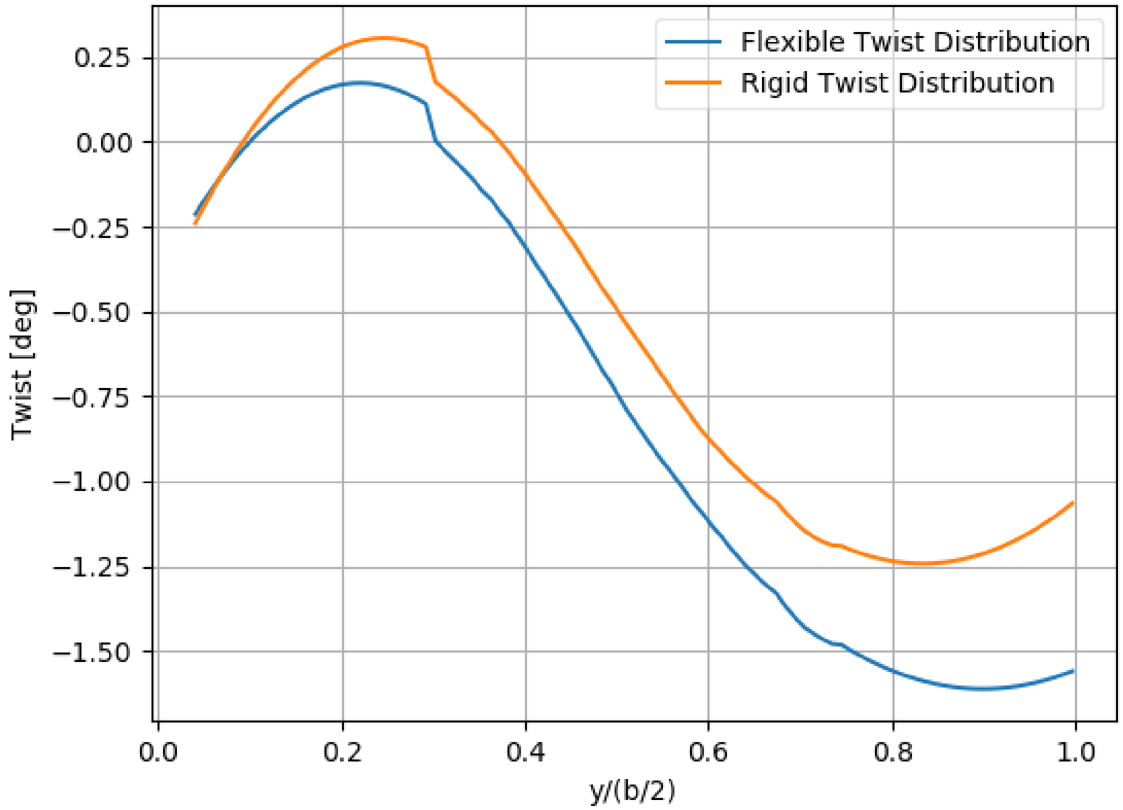


CM BREAKDOWN



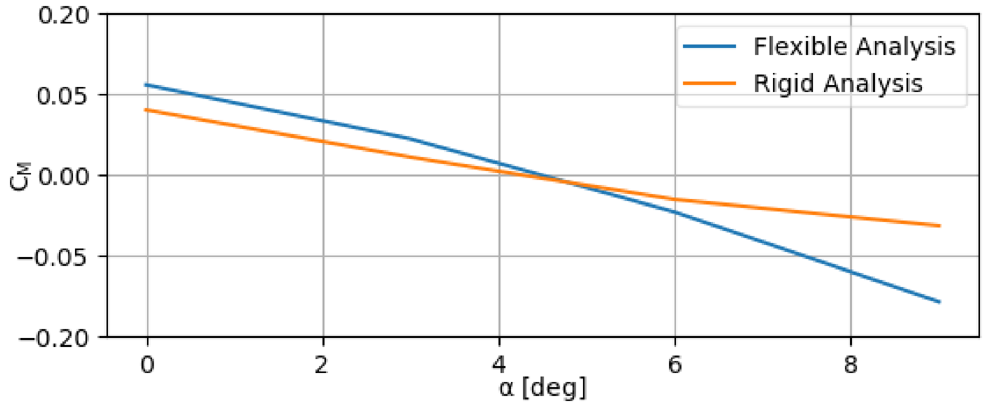
origin pole position:
25% rigid wing mean aerodynamic chord.

Mach number: 0.5
Reynolds number: 4.5*1E6
Physical problem: Eulerian Compressible

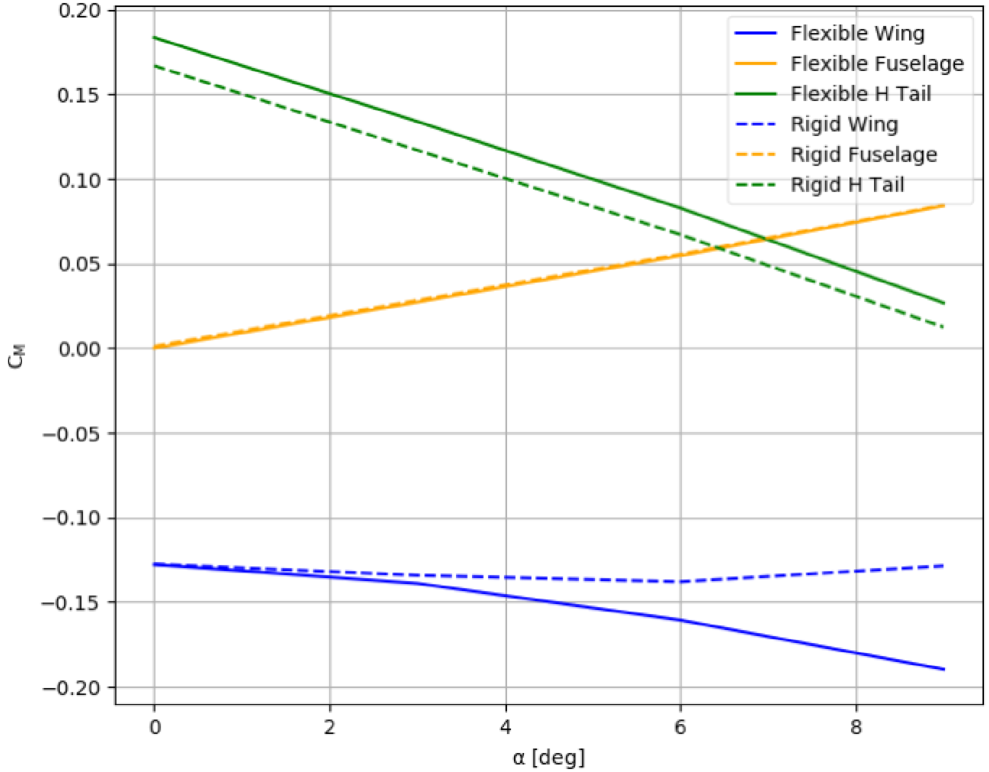


OPTIMALE FLEXIBLE POLAR ANALYSIS

TOTAL AIRCRAFT

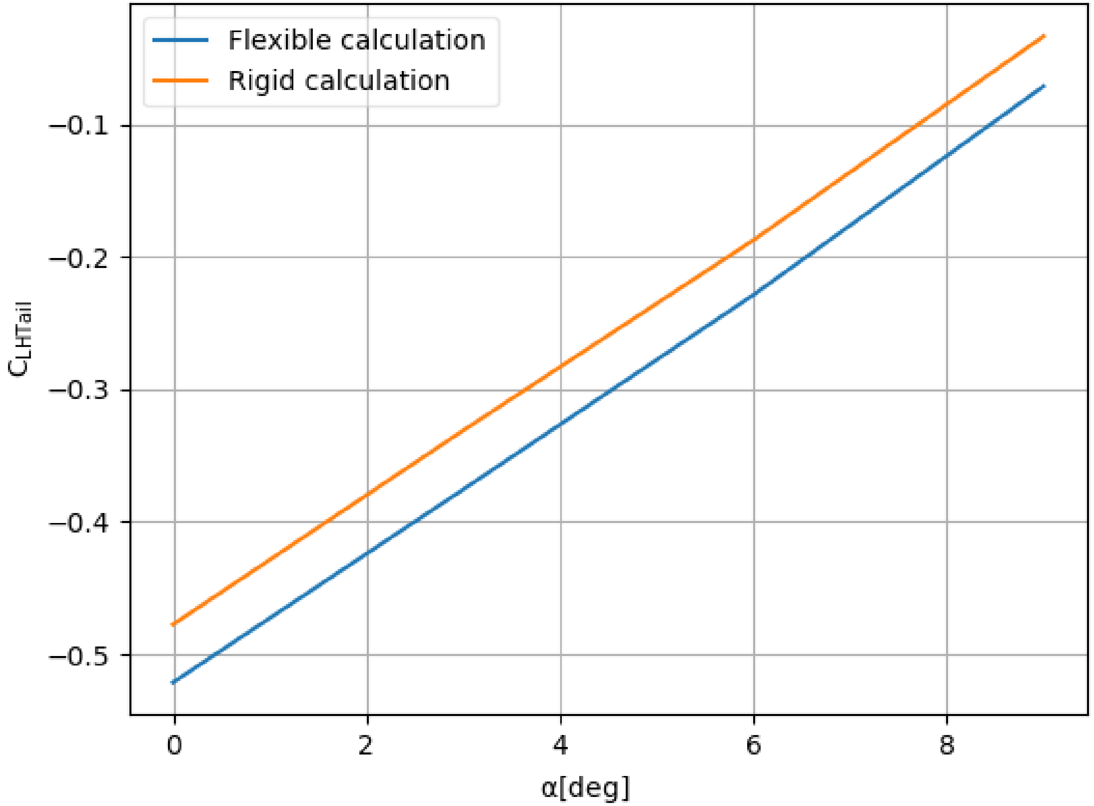


CM BREAKDOWN



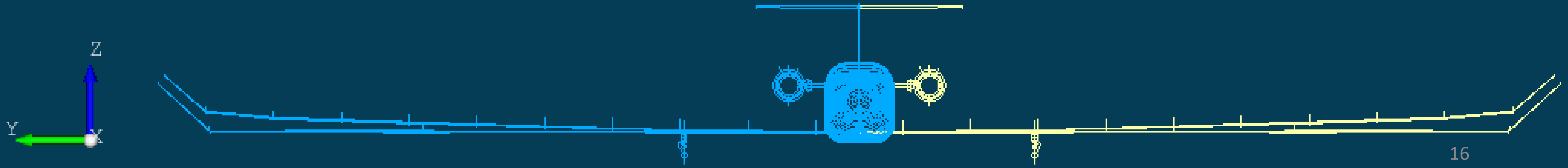
origin pole position: 25% rigid wing mean aerodynamic chord.

Mach number: 0.5
Reynolds number: 4.5*1E6
Physical problem: Eulerian Compressible



CONCLUSIONS AND FUTURE DEVELOPMENTS

- The **automated** aerodynamic and structural processes have been developed and tested in order to demonstrate the feasibility of applying **high-fidelity** methods in multidisciplinary studies performed during early aircraft design phases.
- All the input and output of the developed process are provided through **CPACS format file**. Therefore, all the information generated can be handled by a generic external tool which share the same **collaborative structure**.
- The described methods can be executed with any kind of aircraft configuration. The developed processes posse a high generalization.
- As future development, an aero-structural optimization can be performed. The aerodynamic and structural gradient should be computed using adjoint method. In this way, the gradients with respect to geometry properties can be calculated.



THANK YOU